ESD-TR-70-371

MTR-1905

REAL-TIME CORRECTION OF WIDEBAND OBLIQUE HF PATHS

B. D. Perry

NOVEMBER 1970

Prepared for

DEPUTY FOR PLANNING AND TECHNOLOGY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

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Project 700C
Prepared by
THE MITRE CORPORATION
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Contract F19(628)-68-C-0365

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FOREWORD

This report has been prepared by The MITRE Corporation under Project 700C of Contract F19(628)-68-C-0365. The contract is sponsored by the Electronic Systems Division, Air Force Systems Command, L. G. Hanscom Field, Bedford, Massachusetts.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

ANTHONY P. TRUNFIO, Acting Chief
Development Engineering Division
Deputy for Planning and Technology

ABSTRACT

Another in a series of MITRE experiments involving real-time correction of HF ionospheric paths has been completed. Computer-controlled, real-time correction for path distortions has been achieved over a set of one hop oblique paths in the eastern United States. This correction technique, which utilizes a simple open-loop "measure-then-correct" procedure, provides compensation which remains valid for time periods from a few seconds up to a minute depending on the stability of the ionosphere.

ACKNOWLEDGEMENTS

Credit for the original design of the 24 hr. Clock and the Linear FM and Frequency Correction Programmer belongs to David J. Belknap, presently with Aerotech. Corp. Donald Bungard designed the original receiver including the digital attenuator and various L. O. chains and modified the receiver for the purposes of these experiments. Bruce Twickler designed the new computer interface equipment. Hiram Connell's contribution to software design is apparent from reference 4. Many others aided in direct and indirect ways both in the Advanced Techniques Subdepartment of D-85 under Ronald Haggarty and in department D-86 under William Talley, the project leader.

A special word of thanks goes to Dr. O. G. Villard and the people at Stanford University who once again co-operated with us in every way we could have wished.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

Three years ago Department D-85 undertook a program in adaptive signal processing for ionospheric distortion correction. Early in the program a theoretical technique was devised.[1] To determine the feasibility of this technique, data was gathered on an oblique ionospheric link operated by Stanford University and then the data was analyzed by computer at MITRE. This non-real time computer simulation demonstrated that the basic technique was feasible.[2]

During the second year a vertical HF sounder using a linear FM waveform and employing computer-controlled real time correction for ionospheric distortions was designed and implemented at MITRE Bedford.[3] This equipment provided a means for demonstrating the practicality of real-time correction and has been used as a "building block" for additional experiments.

This paper discusses the results of one set of such experiments. Coherent linear FM Signals were transmitted from remote locations to Bedford, Mass., where they were received, measured, and corrected for ionospheric distortions in real time.

In order to implement this experiment, it was necessary to construct a second programmable linear FM signal generator. This new equipment together with that previously built constitutes a linear

FM oblique HF sounding system together with a computer-controlled adaptive receiver. It was also necessary to modify the original receiver for the reception of oblique instead of vertical signals.

SECTION II

THEORY OF OPERATION

The basic theory of operation of linear FM sounders, as well as further background information on this project, can be found in references 1 and 2. Briefly stated, a linear FM signal is transmitted obliquely, reflected off the ionosphere where it suffers complex distortions, received, and correlated with a replica of the transmitted waveform. The linear FM modulation maps time into frequency. After correlation, the mean of the spectrum of the signal is a measure of the delay of the ionospheric path and the spreading of the spectrum is a measure of the path distortions. Range gating is accomplished by adjusting the receiver bandwidth and center frequency.

A comparison between the result of such an HF path sounding and the desired or ideal signal leads to a determination of the appropriate parameters to be used to implement an approximation to an inverse filter. This filter can then be used to restore the received signal to its original condition (within the validity of the approximation) until such time as the path distortions change due to changes in the ionosphere.

SECTION III

DESCRIPTION OF EQUIPMENT AND ITS ALIGNMENT

A simplified block diagram of the experimental setup is shown in figure 1. More details on each of the two sites, are shown in the next two block diagrams; figure 2 for the fixed station at MITRE Bedford and figure 3 for the MITRE mobile station. A cooperative experiment with Stanford University was also run using Stanford's linear FM signal generator, 100W transmitter and steerable log-periodic antenna (LPA) located at Bearden, Arkansas.

The fixed site equipment is basically the same as that described in reference 3, with three exceptions. First, whereas that vertical sounder had a 4 to 10 MHz bandwidth, for oblique sounding the bandwidth has been increased to cover the frequency range of 5 to 30 MHz. Secondly, obliquely directed LPA's are now being employed. A horizontally polarized LPA looks West and a cross polarized pair of LPA's are oriented South by Southwest. Finally, a different computer is now part of the system. The Hewlett-Packard hp2115A has been programmed to perform real-time correction and FFT spectrum analysis as well as recording of all data and offline display of amplitude, phase, and transforms of multiple-sweeps (time-history plots). These programs are described in detail in Reference 4.

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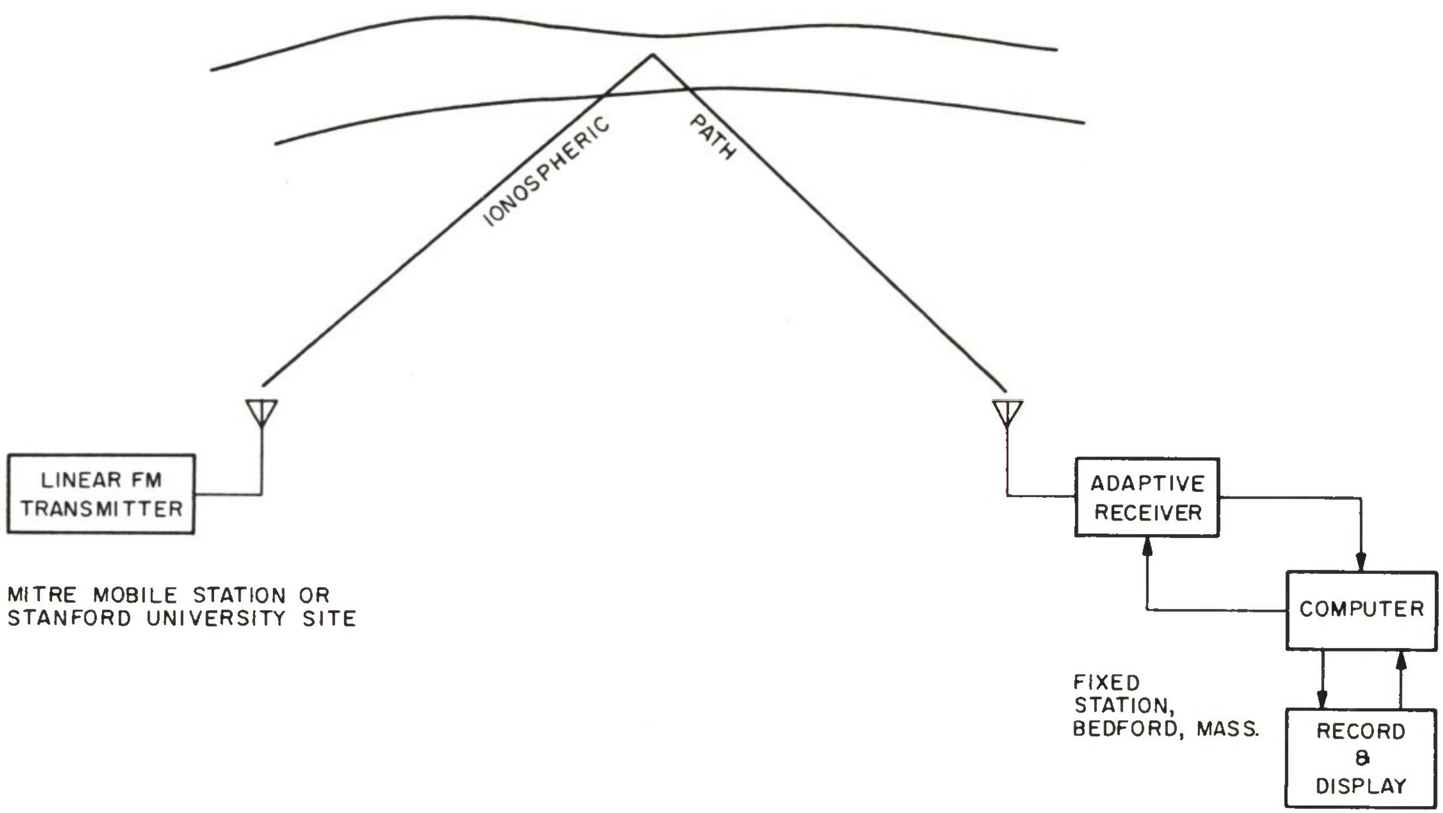

Figure 1 ONE-WAY OBLIQUE HF SOUNDER WITH DISTORTION CORRECTION

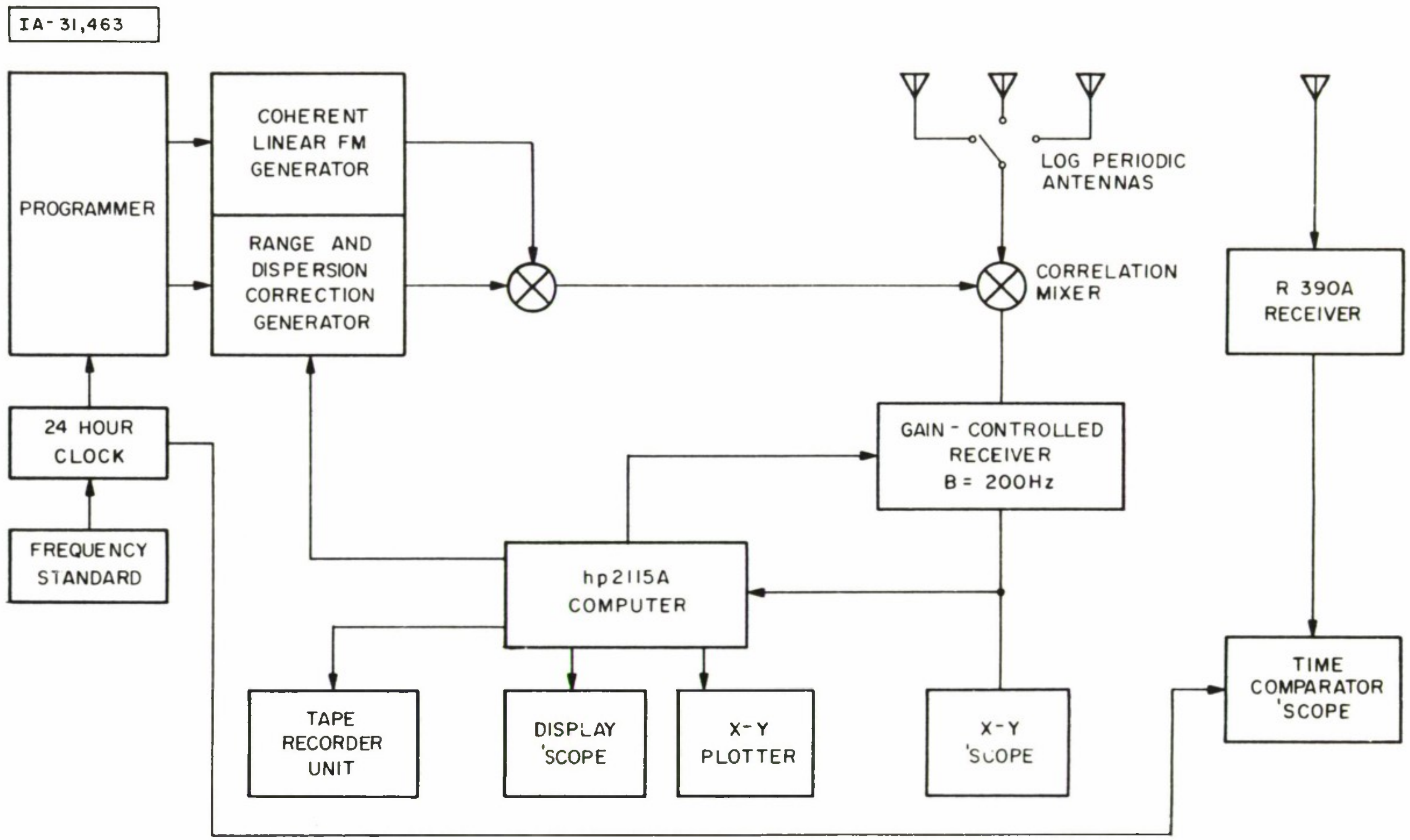

Figure 2 SIMPLIFIED BLOCK DIAGRAM OF FIXED STATION AT BEDFORD, MASS.

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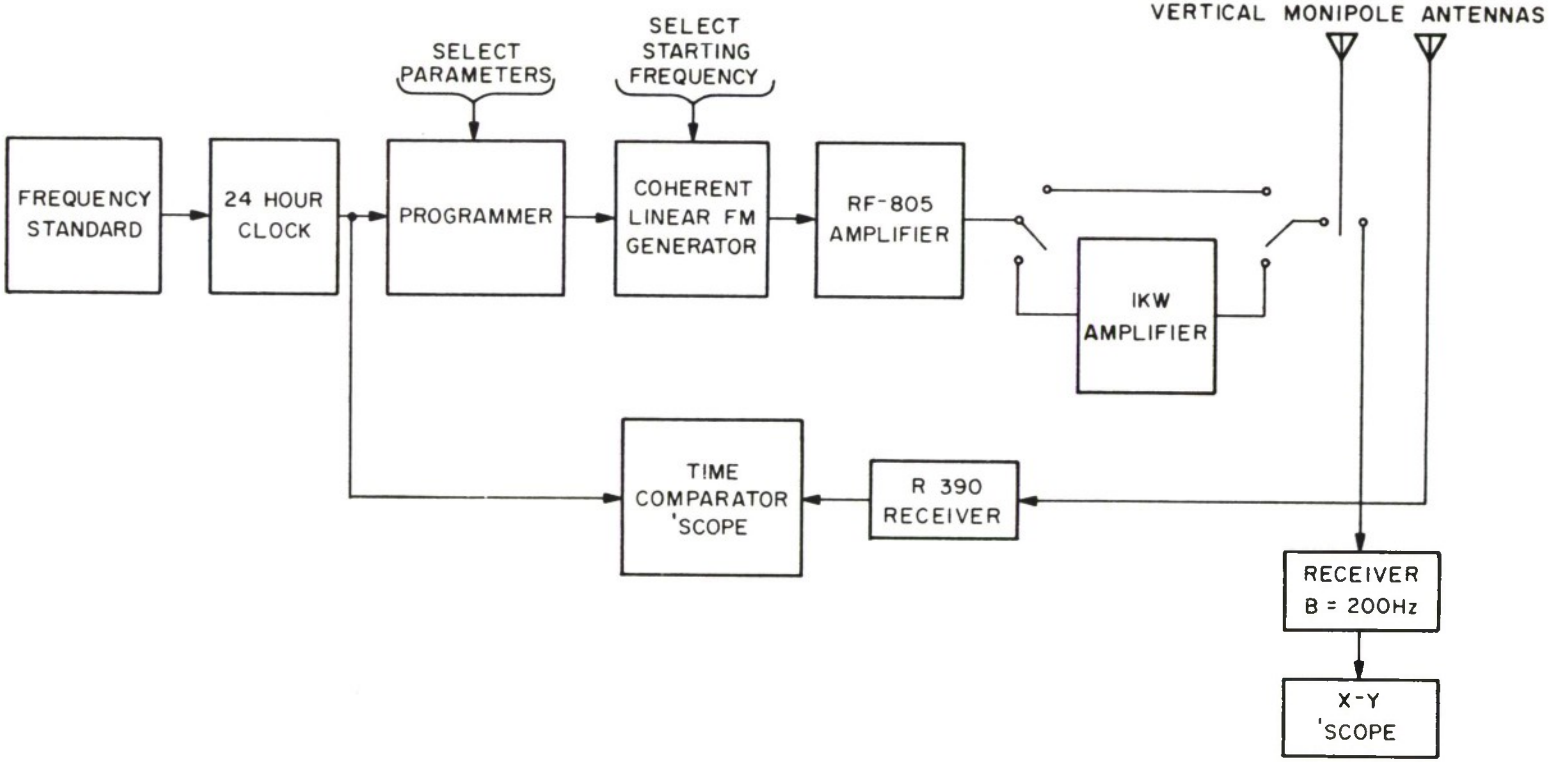


Figure 3 SIMPLIFIED BLOCK DIAGRAM OF MITRE MOBILE STATION

The mobile equipment, with the exception of a 1 kW broadband amplifier, is all housed in a small panel truck. The clock, linear FM programmer, and modified frequency synthesizer are all identical to the Bedford equipment and are described in detail in reference 3. An RF Communications type RF805 broadband amplifier provides up to 10 watts of output power. An adjustable vertical monopole antenna is mounted on the roof of the truck. It has a VSWR of better than 1.3 over any selected 1 MHz band between 10 and 30 MHz.

In order to synchronize the two sites, R-390A communications receivers are used to obtain timing signals from either WWV in Colorado or CHU in Ottawa. The 1 second time marks from, for example, WWV are displayed relative to 1 second time marks of the system's 24 hour clock. The clock is advanced until time synchronization is achieved. Increments as fine as 100 μsec are available.

It is also important that the two frequency standards be as accurate as possible, otherwise, even assuming perfect stability, the starting times of the two sweeps will drift (one relative to the other) and the FM slopes will not be identical. Frequency accuracy is achieved by tuning the main receiver to, say, WWV and observing the signal on an X-Y oscilloscope. For this purpose a second quadrature channel receiver of 200 Hz equivalent IF bandwidth is used in the mobile station. The standard's frequency is then adjusted until the phase difference as observed on the scope averages zero over several seconds. The only unresolved error is that due to doppler shift on

the WWV signal caused by ionospheric drift. Better frequency accuracy can be achieved via Loran stations and will be incorporated if this appears to be necessary. Data taken thus far, however, does not indicate a need for better synchronization. In any event, in these experiments care can be taken to "re-synch" on WWV between runs, thus preventing errors from accumulating for more than a few minutes.

In all cases the system's programmers were set up so that 900 millisecond sweeps were repeated every second. Clock advance at one site or the other and/or manual local oscillator offset were used to align the Bedford local oscillator FM sweep with that of the incoming signal so as to minimize path delay effects and produce a fairly low mean frequency at the receiver output. The programmer at Bedford also commands alternate 1 second intervals to be "uncorrected" and "corrected." Various starting frequencies were used and sweep rates of .5, 1.0, 2.0, 2.5, and 5.0 MHz/sec were selected via the programmers. Before recording data, uncorrected signals were observed for several different frequency bands so as to determine the "quality" of the HF path for that time period and the approximate Maximum Usable Frequency. Switches on the computer console are used to begin recording and stop recording. In addition, two modes of operation can be selected; either alternate corrected and uncorrected sweeps as determined by the Bedford programmer or a multiple set of corrected sweeps all referred to the first uncorrected sweep in the sequence.

In this second mode, corrected sweeps occur every two seconds, interspersed with uncorrected sweeps. These formats are sketched in Figure 4.

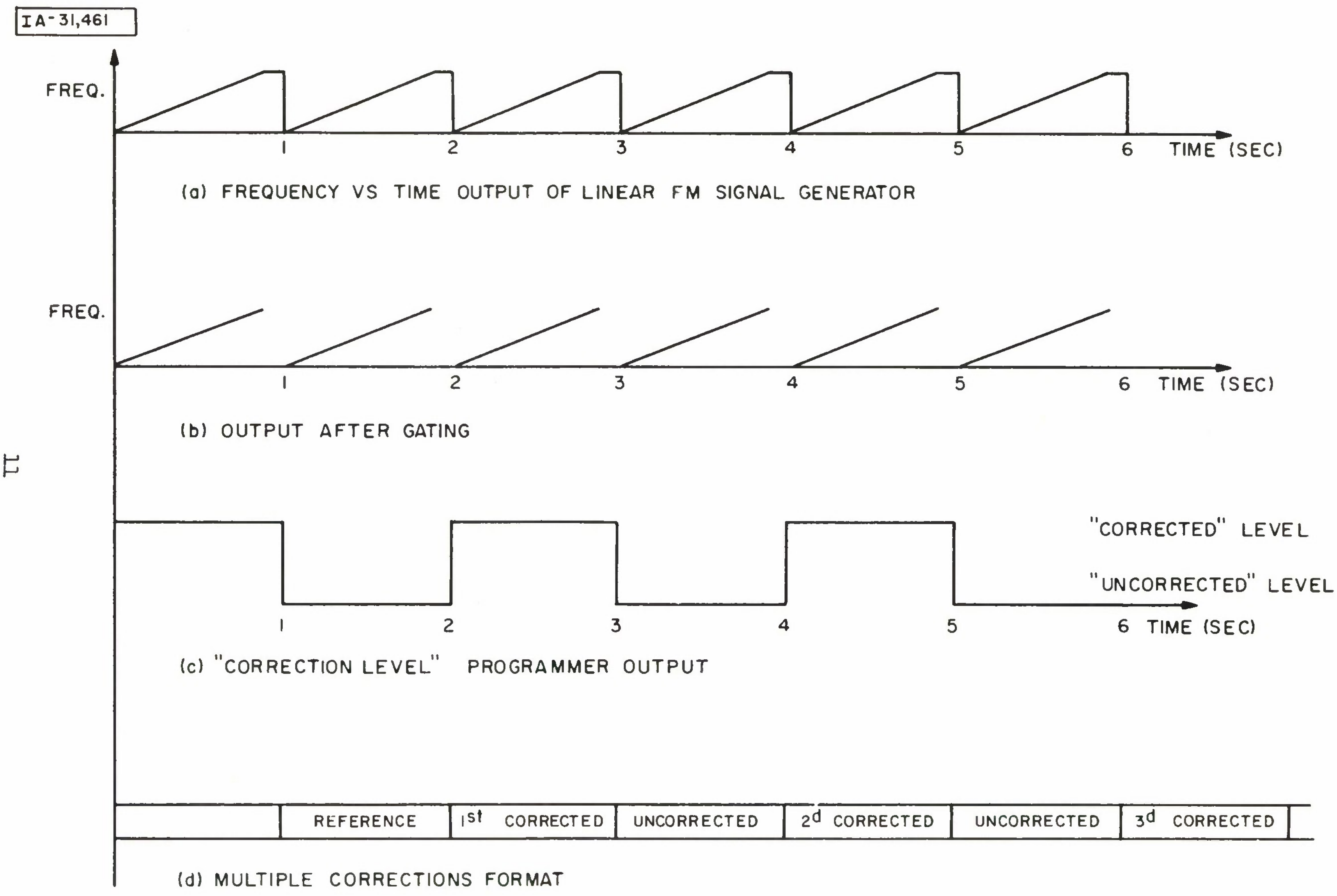


Figure 4 TIMING DIAGRAM

SECTION IV

ANALYSIS OF DATA

Paths over which these one-way oblique tests with real-time correction were run are shown in Figure 5. Data was taken in two modes; about 1400 records of alternate corrected and uncorrected sweeps, and about 3500 records of multiple corrections referred to one uncorrected sweep. Only multiple corrections are shown in this paper as they are the most meaningful and present the data in compact form. Of the total of 4900 records, the Fourier transforms of all were displayed for visual inspection, and photographs were taken of some 240. In addition X-Y plots were made using a Calcomp plotter of 32 multiple correction sets, each accounting for about 22 additional records. In this way over half of the multiple corrections have been either photographed or recorded on paper. This paper contains a representative sampling of the X-Y plots. They are grouped as follows: 1) Transmitter starting frequency as the only variable, 2) Receiving antenna polarization as the only variable. 3) Transmitter location as the primary variable and 4) Two miscellaneous plots.

The first tests were conducted in October 1969 in cooperation with Stanford University's Radio Physics Laboratory. Stanford transmitted linear FM sweeps at rates of 1.0 and 2.5 MHz/sec repetitively every second from their site in Bearden, Arkansas between 10 and 11 in the morning (EDT.) Four starting frequencies were used: 11.1,

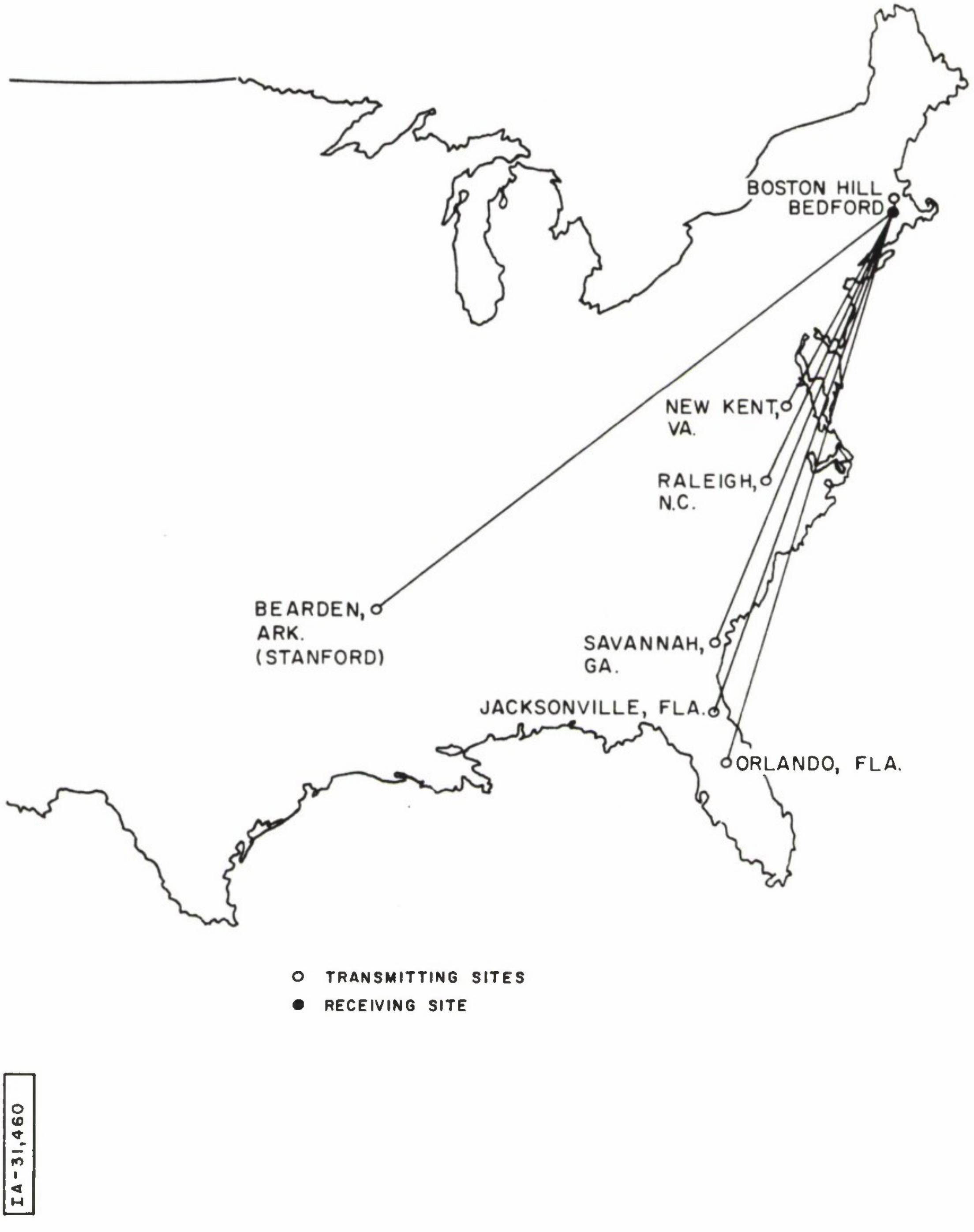


Figure 5 SITE LOCATIONS

15.1, 19.1, and 23.1 MHz. The MUF was generally above 24 MHz. These results are shown in Figures 6, 7, 8, and 9. "One plus cosine" weighting was employed to suppress sidelobes. These results indicate that nearly ideal corrections can be obtained for up to several seconds for at least three of the four frequency bands. The ideal range resolution for these cases is 0.44 μsec.

Prior to the use of the MITRE mobile station for further tests, a calibration run was made. A linear FM signal was transmitted from the mobile station to the Bedford receiver with the two antennas less than 100 ft. apart. The transform of the receiver output was then compared with the transform of a sinusoid with both displayed on a logarithmic scale. Sidelobes due to signal phase and amplitude errors are more than 20 dB down. These results are shown in Figure 10. In addition, the deramped calibration signal was viewed on a polar display as shown in Figure 11. Phase errors are estimated at 10^{o} RMS and amplitude errors at .5 dB RMS. (The ideal result would be a single spot). These results indicate that the calibration signal is a close approximation to the ideal, and therefore most measured errors can be attributed to either ionospheric distortions or antenna mismatching. Although broad band antennas were used wherever possible, some antenna errors will inevitably remain.

In December 1969 a series of tests were run between points in the South Atlantic states varying between 700 and 1800 Km ground range and Bedford, Mass. (See Figure 5). One sample from each path

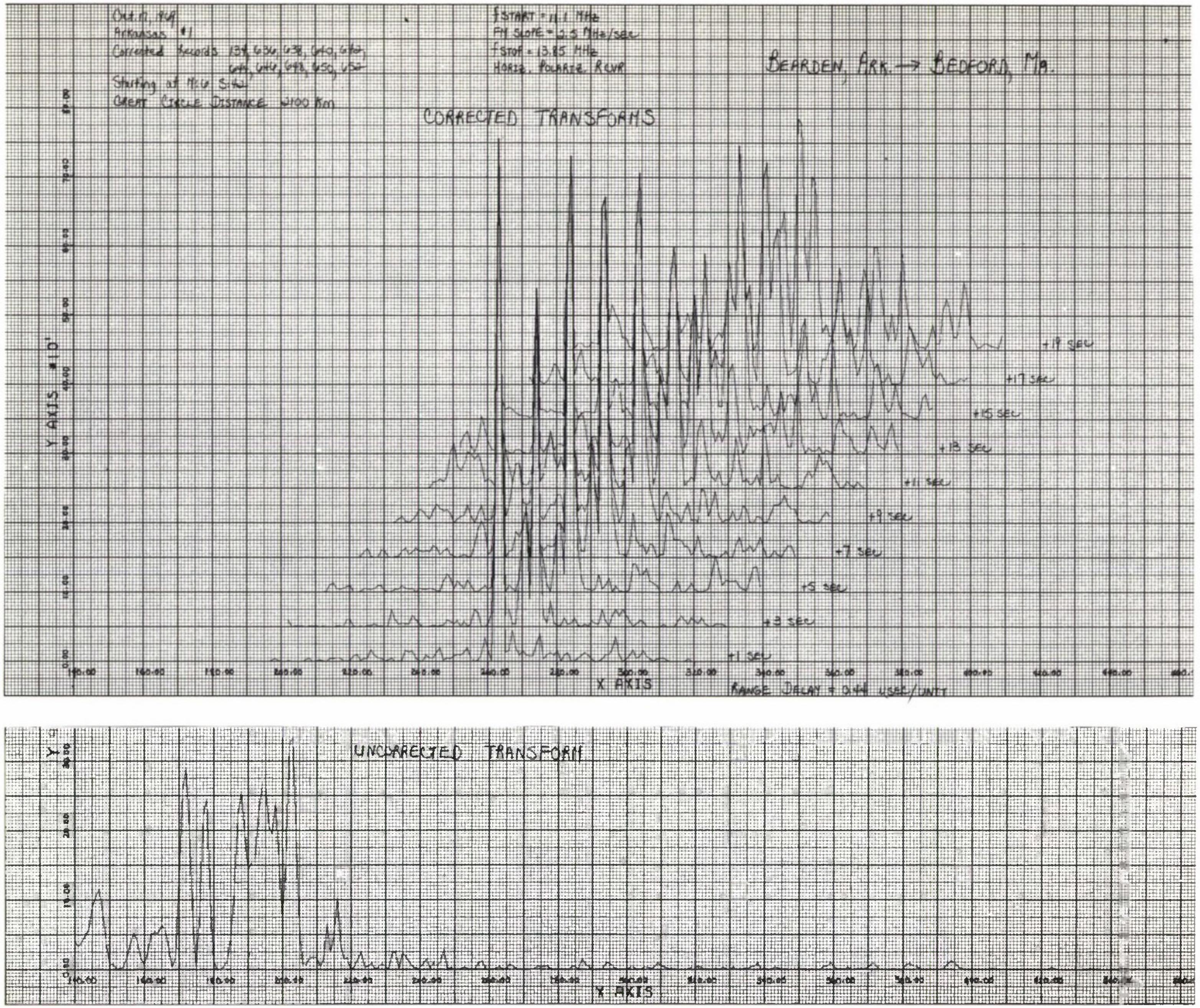


Fig. 6. Bearden Ark to Bedford. 11.1 to 12.0 MHz

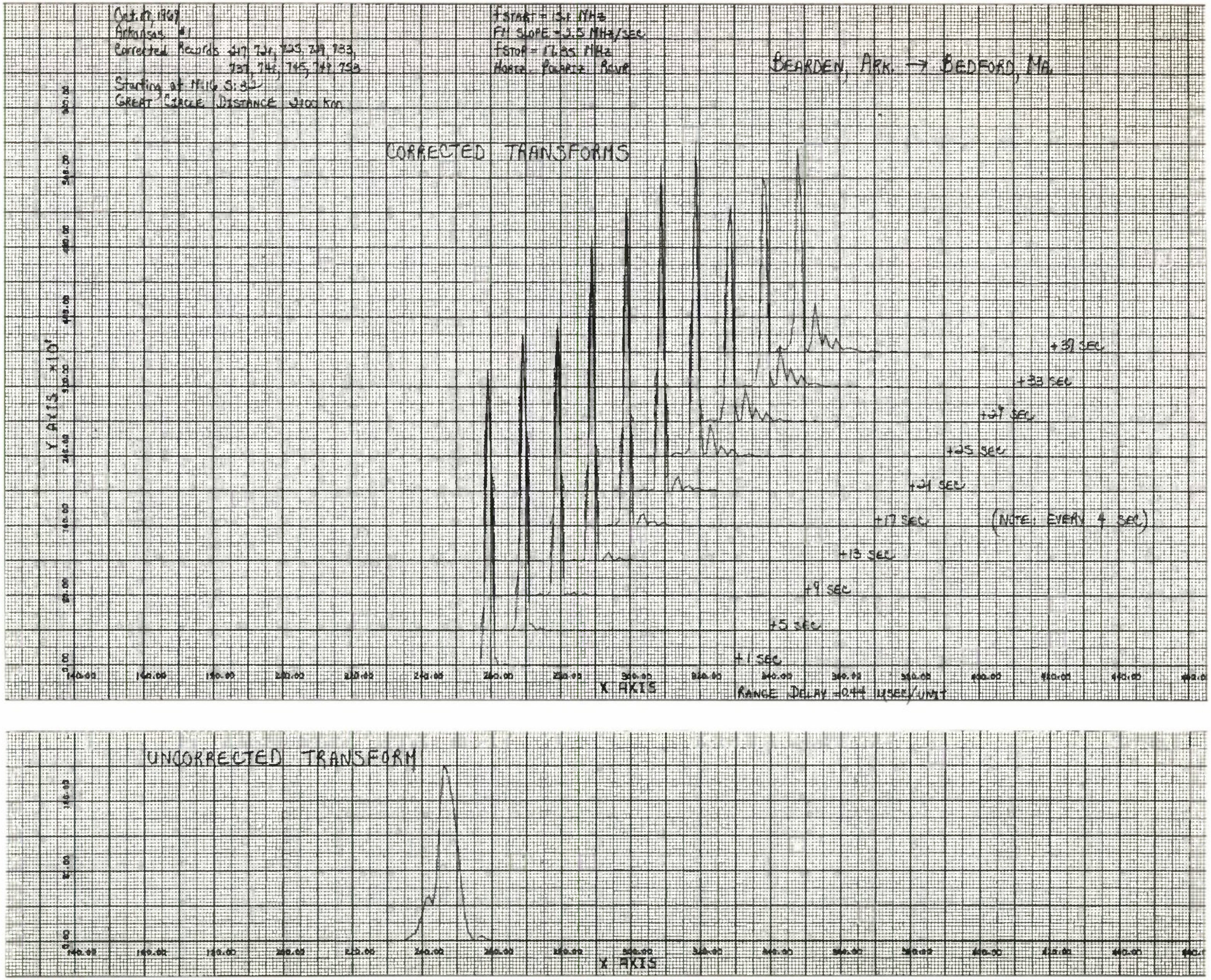


Fig. 7. Bearden, Ark to Bedford. 15.1 to 16.0 MHz

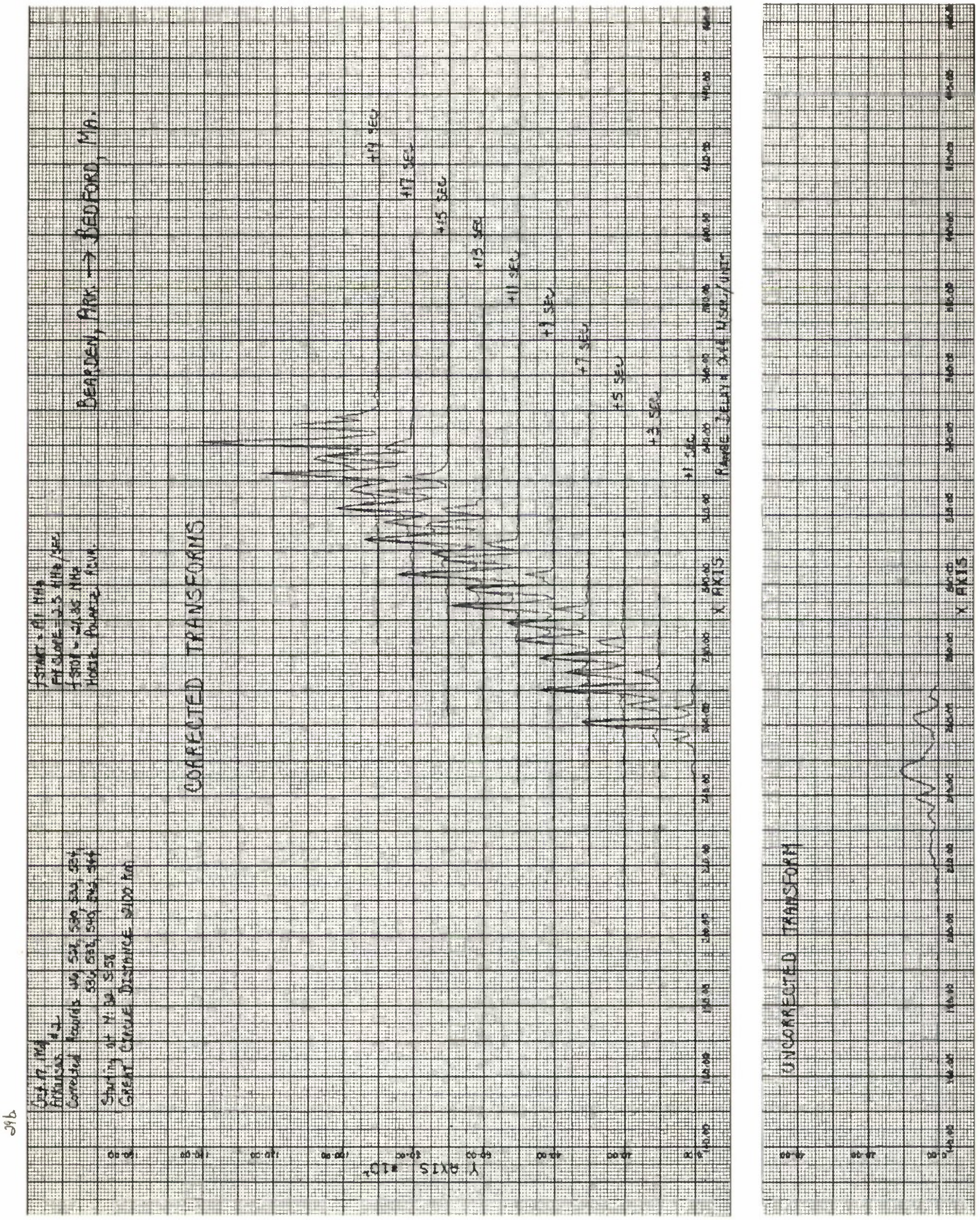


Fig. 8. Bearden, Ark to Bedford. 19.1 to 20.0 MHz

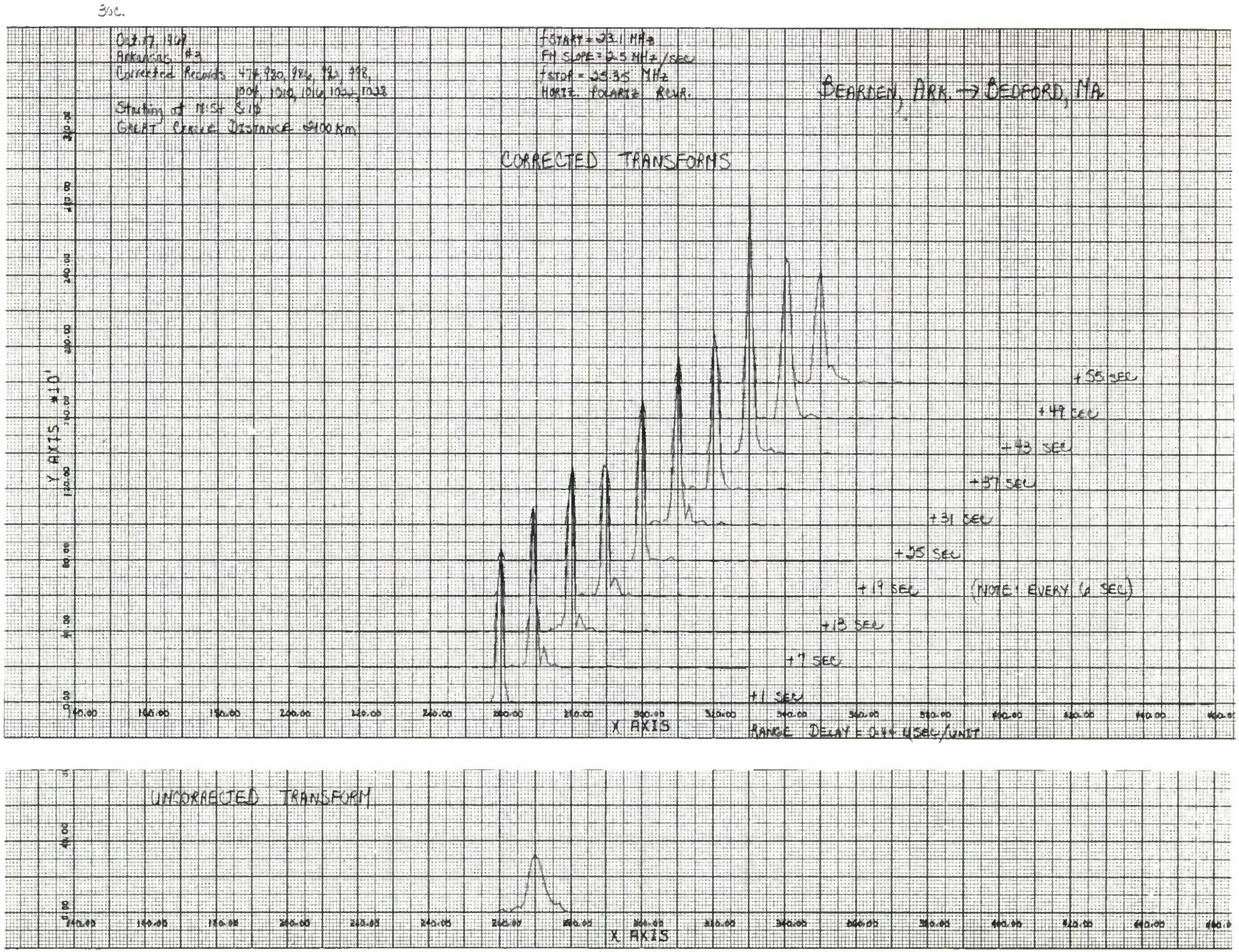
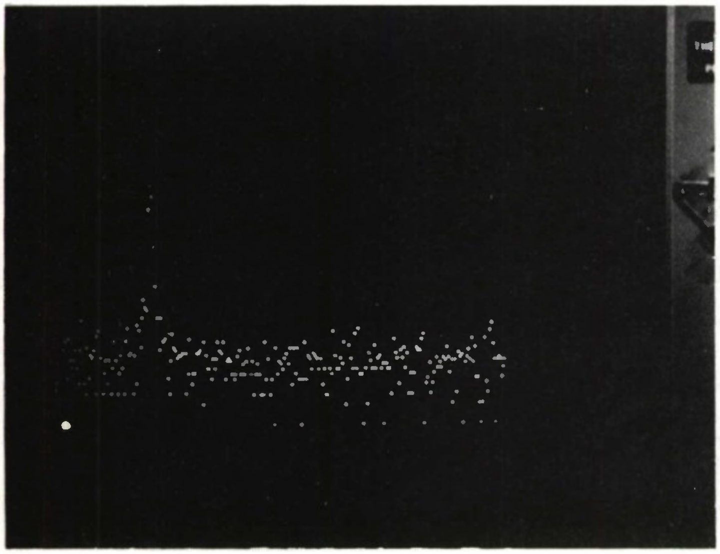
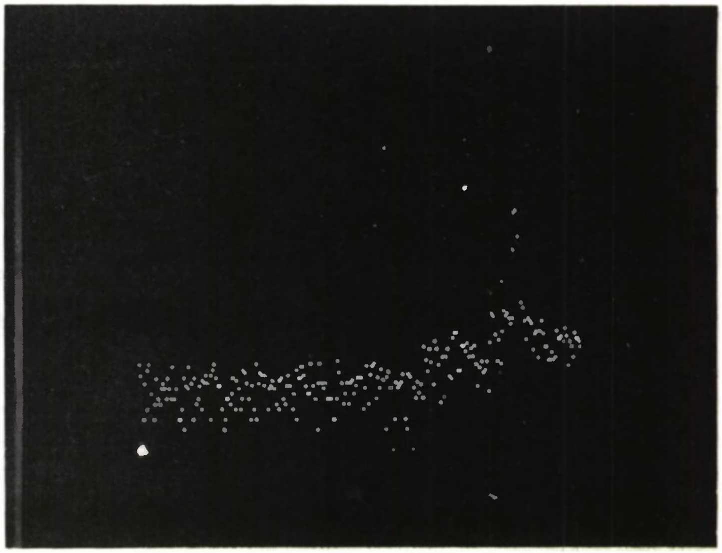


Fig. 9. Bearden, Ark to Bedford. 23.1 to 24.0 MHz



(a) SINUSOID



(b) CALIBRATION SIGNAL

Figure 10 LOG OF WEIGHTED TRANSFORM

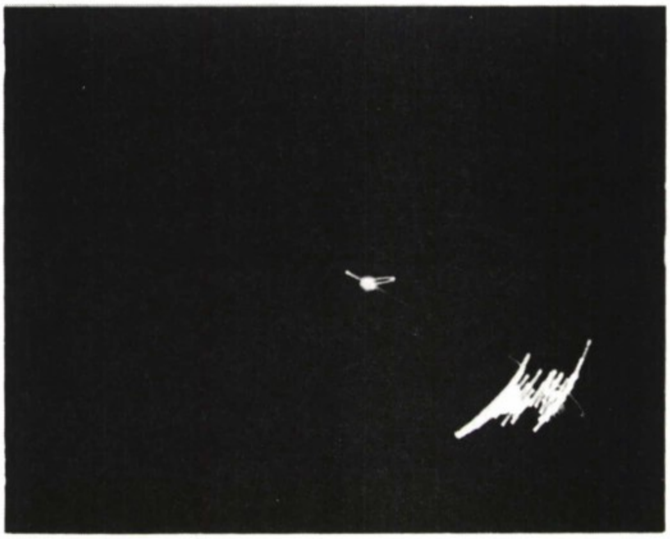


Figure 11 POLAR DISPLAY OF CALIBRATION SIGNAL

is shown in Figures 12, 13, 14, 15, and 16. In all cases the sweep rate was 1 MHz/sec and a circularly polarized receiving system was used.

In Figures 17, 17, and 19 for the path from Savannah, Ga. to Bedford, Mass. all parameters are the same except receiving antenna polarization. It can be seen that, when circular polarization is used, thus suppressing one of the two magneto-ionic components, the corrections hold for a longer time. This verifies the feeling held previously that the interference effect between the ordinary and extra-ordinary rays is the prime cause of oblique HF path instability.

Figure 20 is one example of a 5 MHz/sec sweep rate over a 4.5 MHz band. The range window is only 40 μsec and it is relatively unusual to find conditions such that the uncorrected signal remains within this range window over this much bandwidth.

The last set of results is somewhat anomalous compared with the other data. It is for a one-way path by way of the ionosphere from Boston Hill in Andover, Mass. to Bedford, Mass. The line-of-sight distance is only 20 Km so it hardly qualifies as oblique. It is essentially a bistatic vertical sounding. Several runs were made using this path as a final "shakedown" before the mobile station departed for the South. One such run is shown in Figure 21. It should be noted that the ionospheric distortions being corrected over this vertical (up-down) path are about three times more severe versus frequency than they are for the typical oblique path.

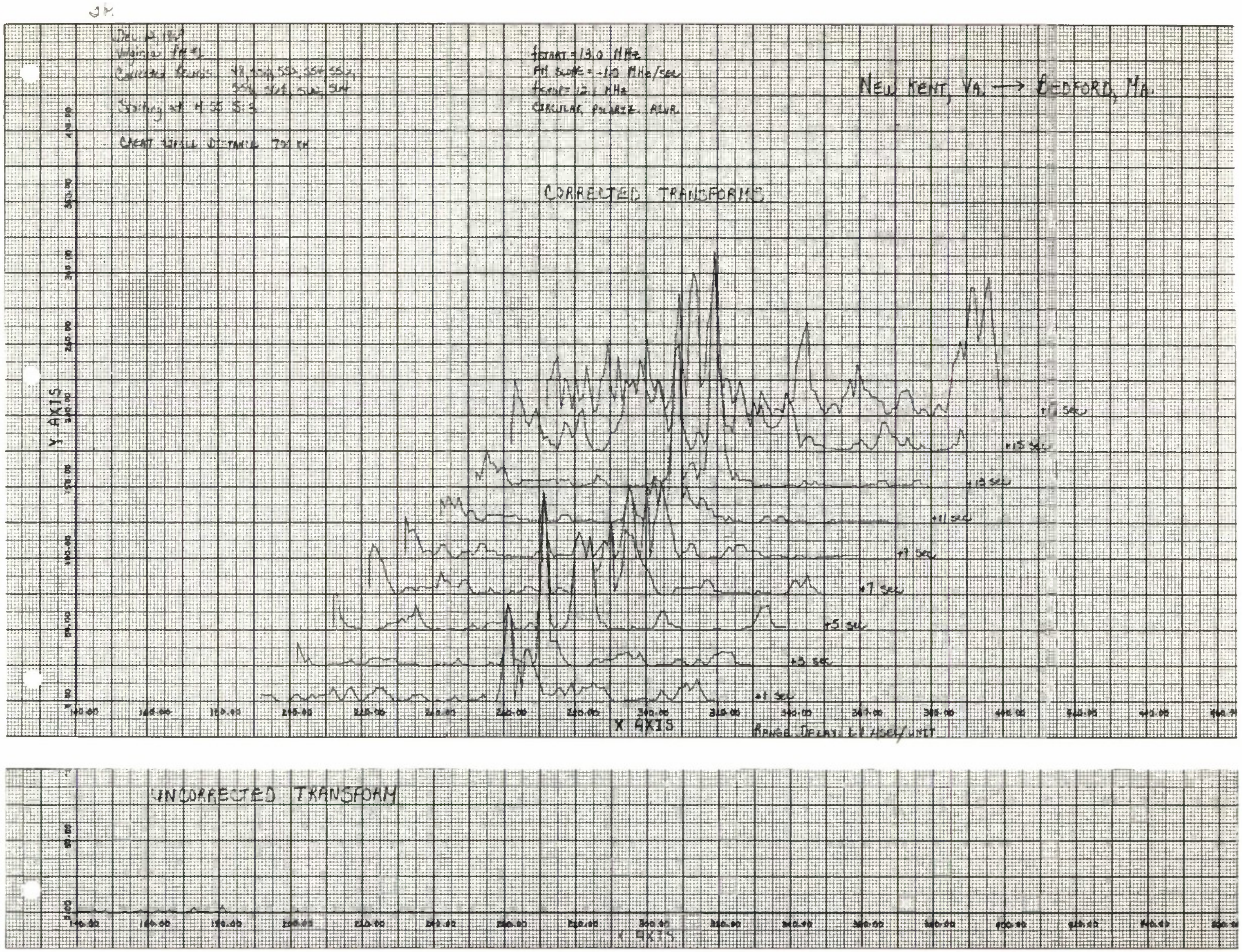


Fig. 12. FM Slope: -1 MHZ/sec. Va. to Mass. 700 Km Ground Range

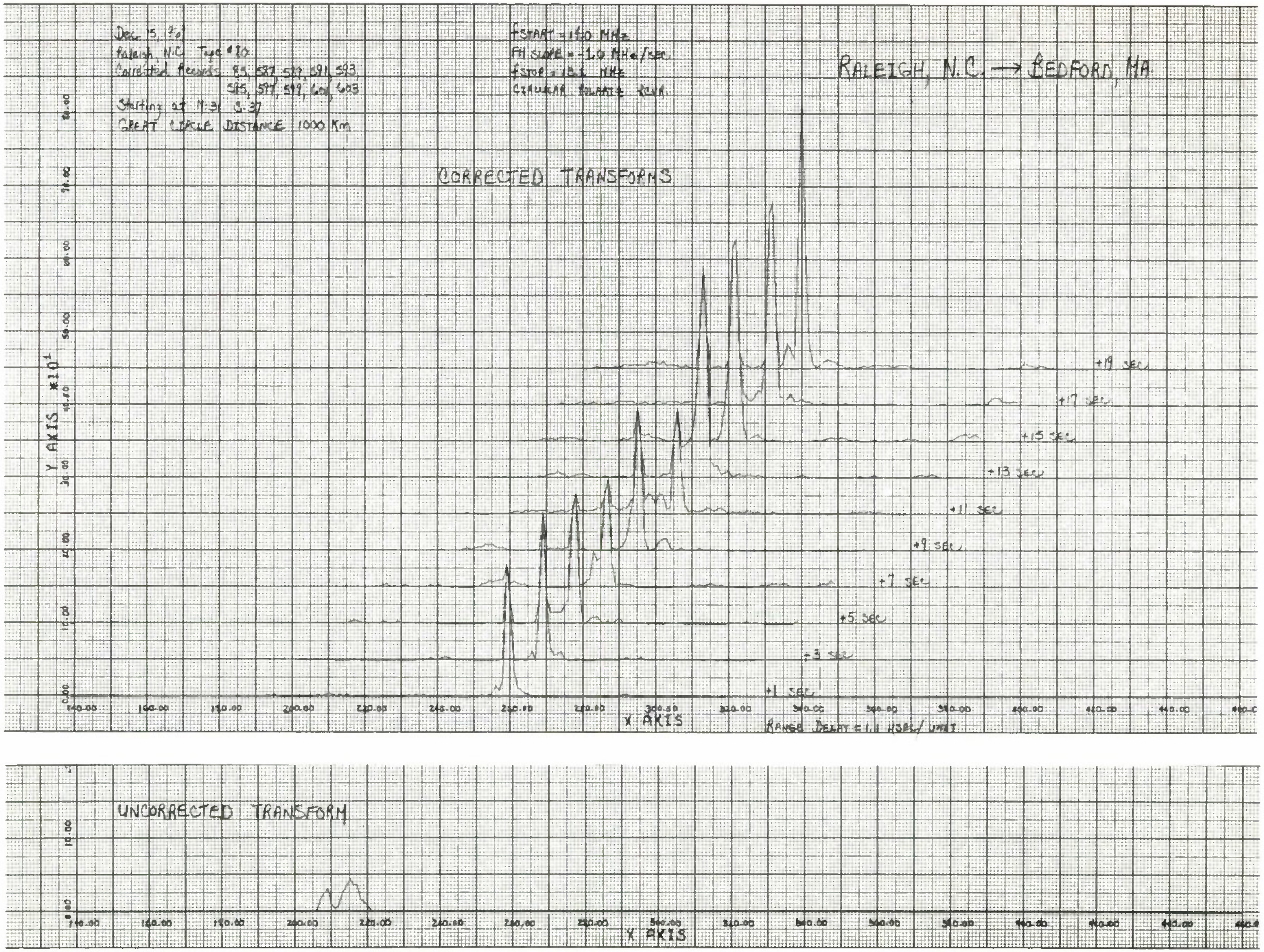


Fig. 13. FM Slope: -1 MHz/sec. N. C. to Mass. 1000 Km Ground Range

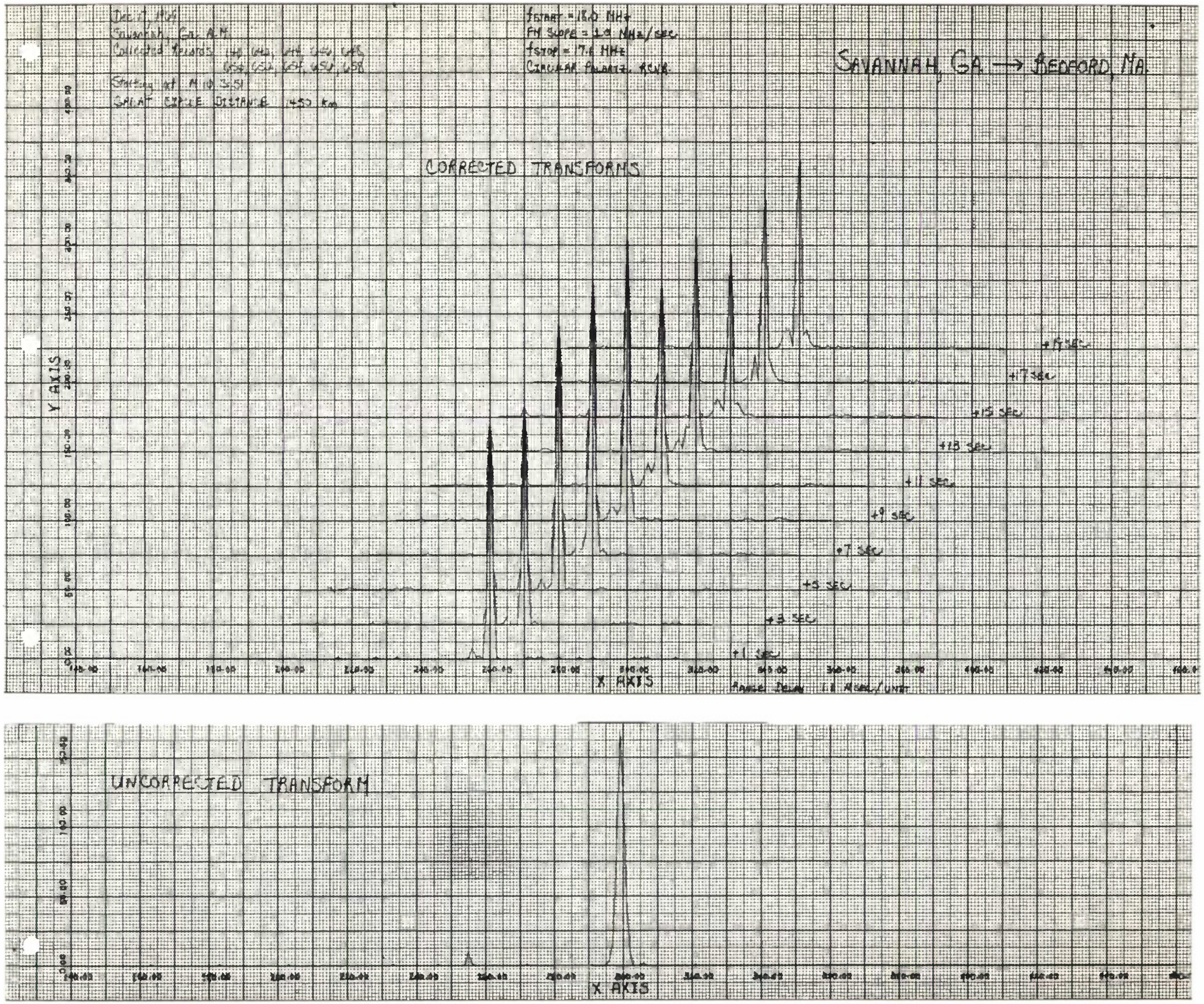


Fig. 14. FM Slope:-1 MHz/sec. Ga. to Mass. 1450 Xm Ground Range

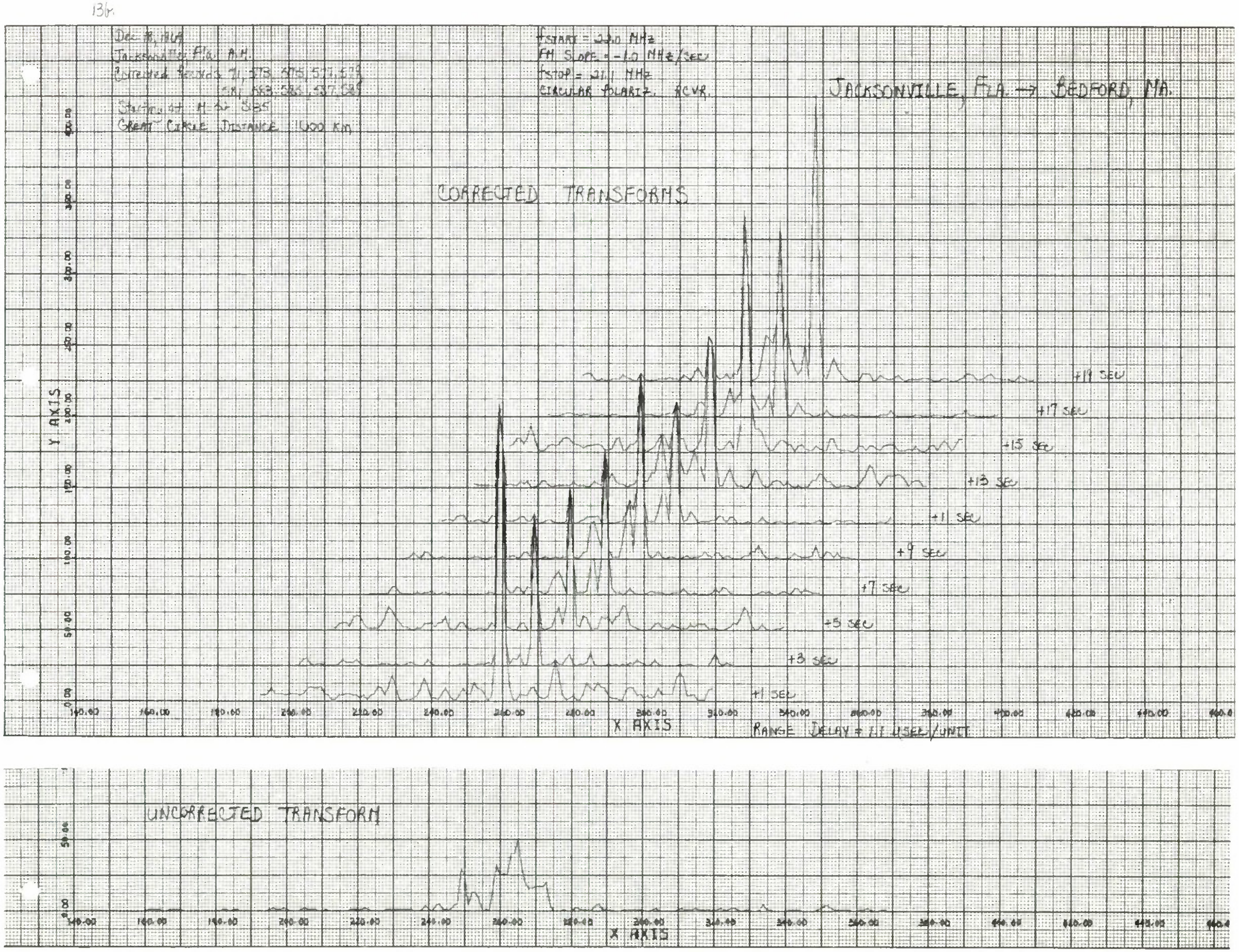


Fig. 15. FM Slope: -1 MHz/sec. Fla. to Mass. 1600 Km Ground Range

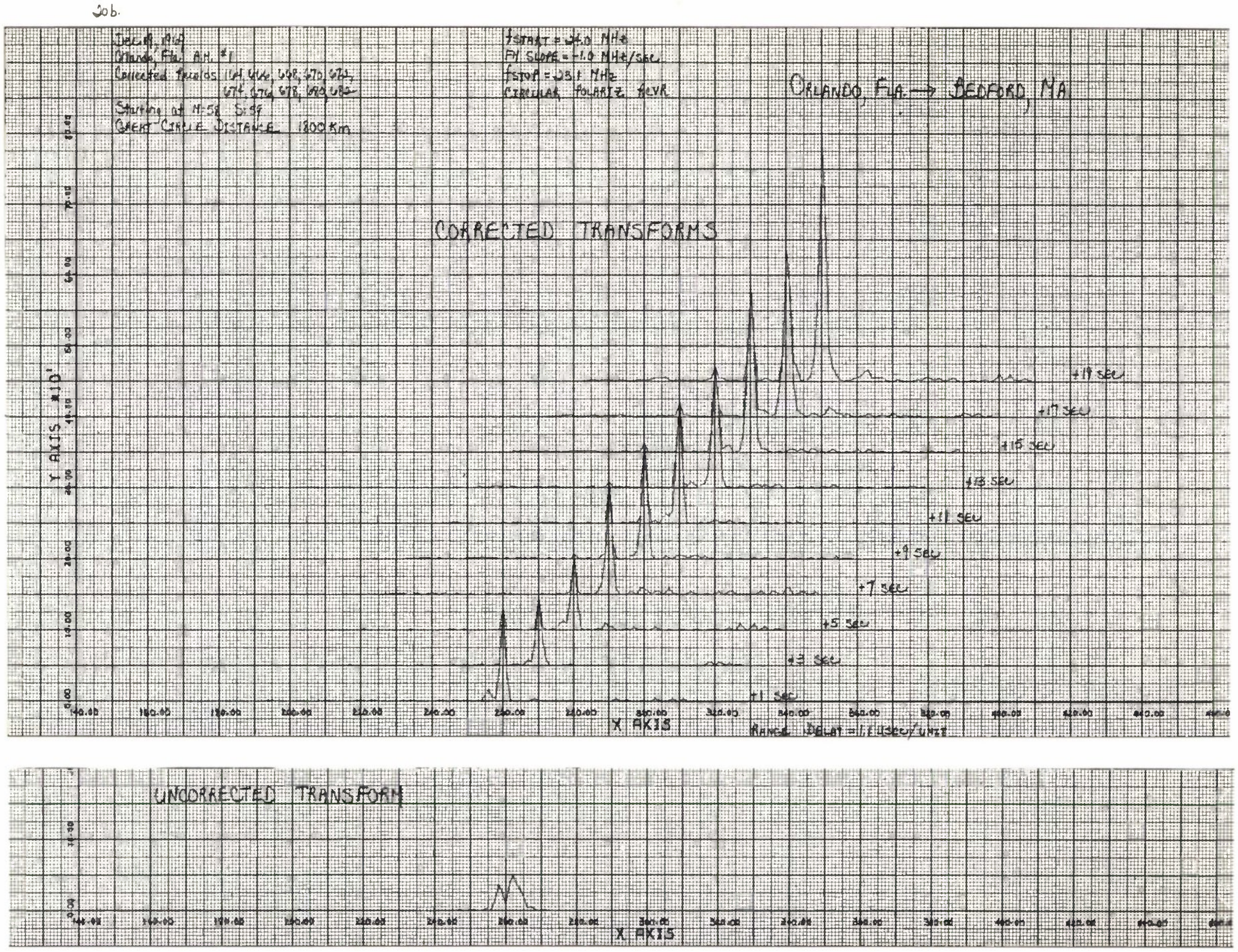


Fig. 16. FM Slope:-1 MHz/sec. Fla. to Mass. 1800 Km Ground Range

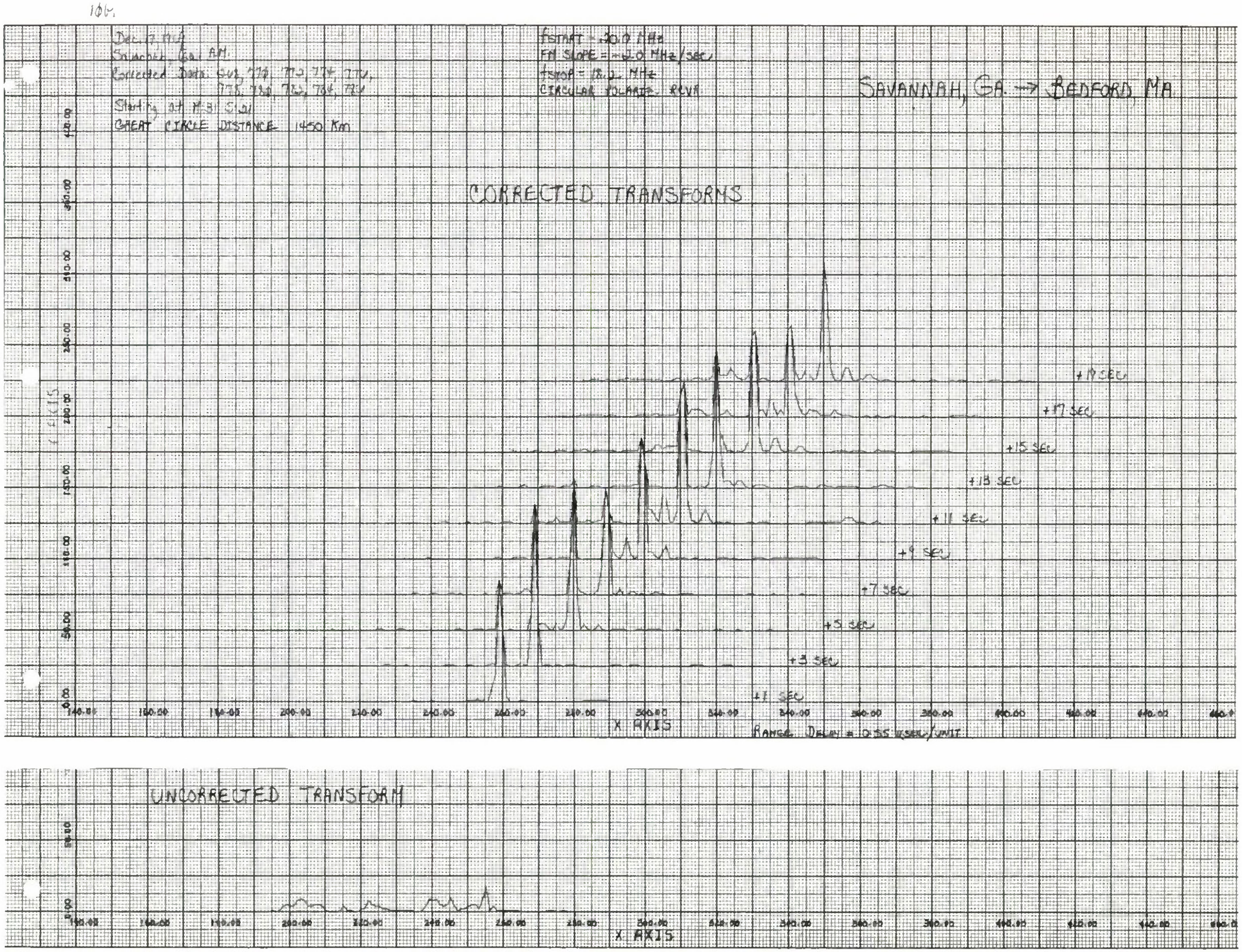


Fig. 17 Savannah, Ga. to Bedford. Circular Polarization

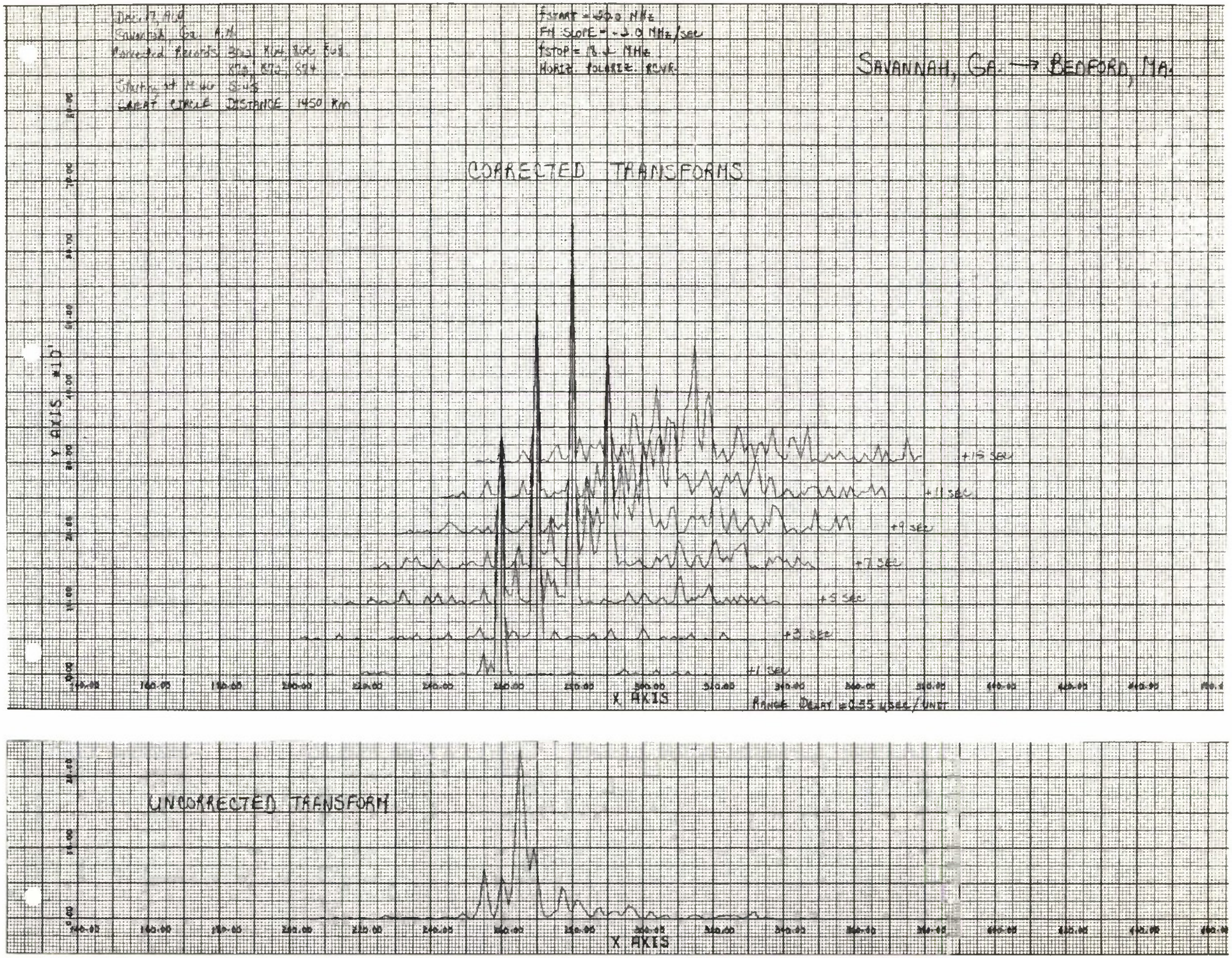


Fig. 18. Savannah, Ga. to Bedford. Horizontal Polarization

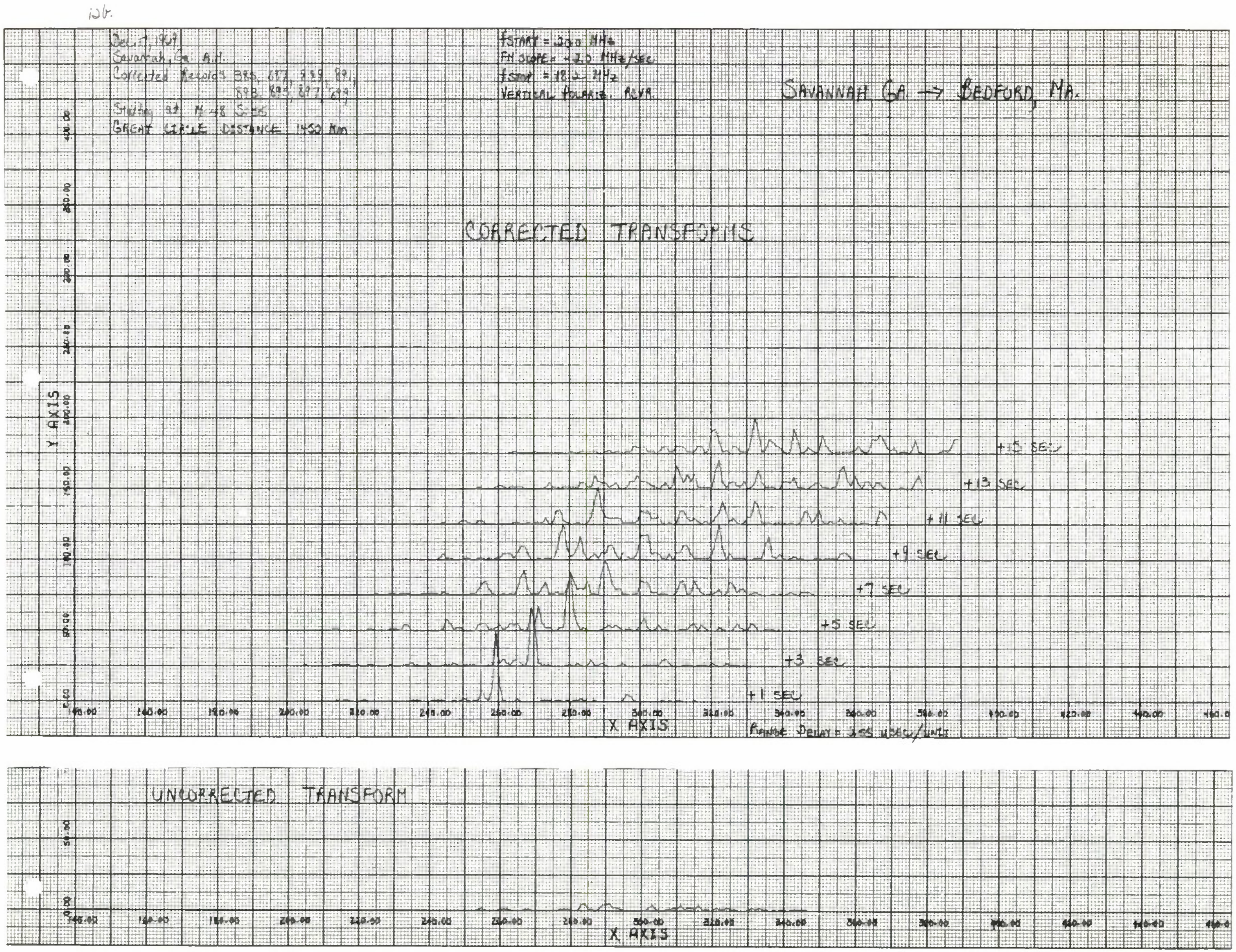


Fig. 19. Savannah, Ga. to Bedford. Vertical Polarization

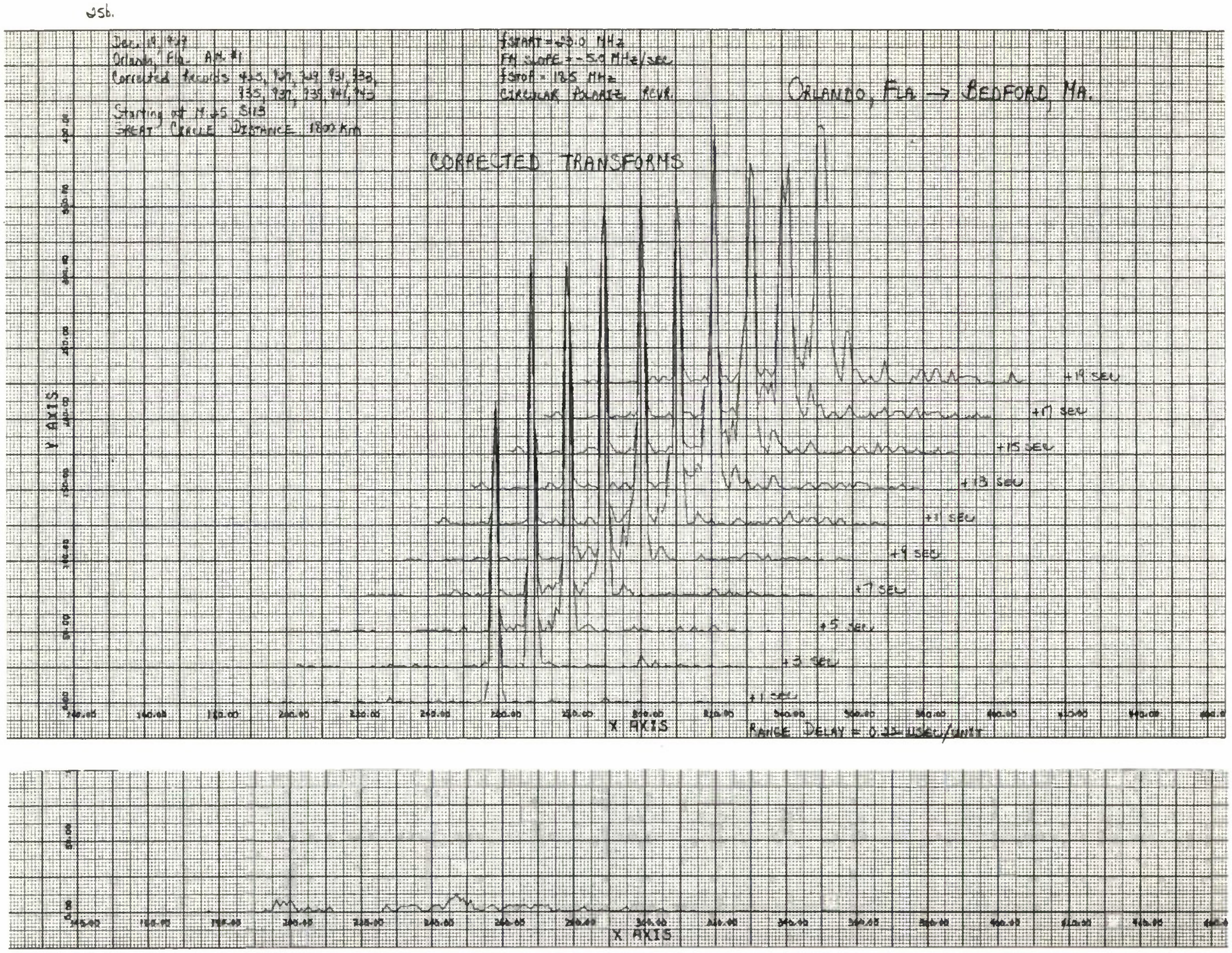


Fig. 20. Orlando, Fla. to Bedford Sweep Extent = 4.5 MHz

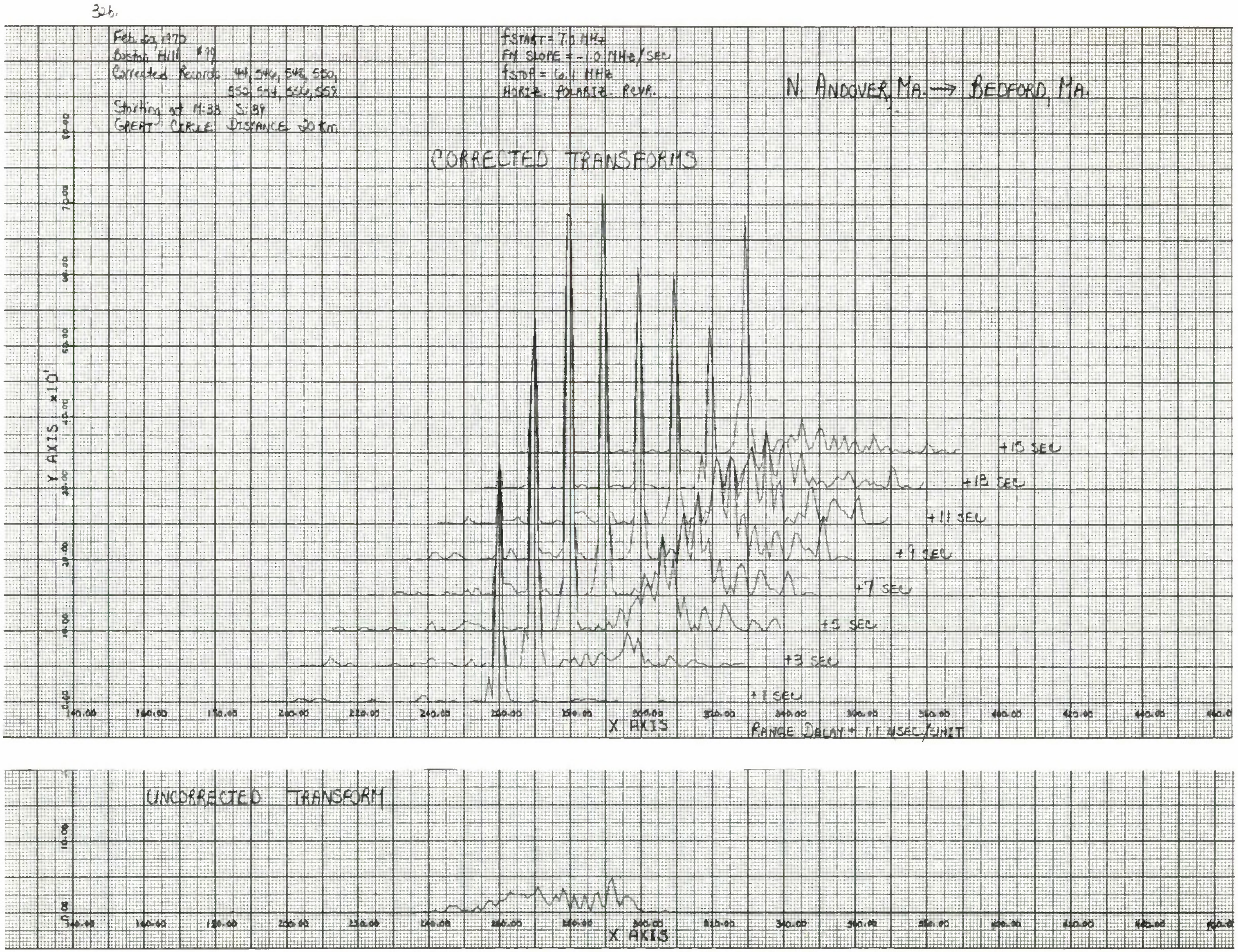


Fig. 21. Bistatic Vertical Sounding

The line of sight signal was also independently observable by changing the location of the range window through receiver L. O. tuning. Knowing the FM slope and measuring the frequency difference between the settings of the receiver local oscillator required for tuning first to the ionospheric signal and then to the line-of-sight signal, the path delay can be computed. For the data shown in Figure 21, the path delay was 1.83 msec. This corresponds to a virtual height of 265 Km.

SECTION V

CONCLUSIONS

This set of experiments shows that real-time correction of one-hop, one-way, oblique HF signals can be achieved and that once the corrections are computed, they hold for anywhere from a few seconds to one minute, depending on the stability of the ionosphere, bandwidth, and polarization of the receiving system. Thus to date the following experiments have been successfully completed:

1) Non-real time correction of one-way oblique path

2) Real-time correction of vertical (up-down) path

3) Real-time correction of one-way oblique path

The next experiment to be conducted will be to attempt real-time correction of a two-way oblique path (over and back via a repeater).

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2. D. J. Belknap, D. R. Bungard, L. A. Hart, B. D. Perry; "Linear FM Vertical Sounder for Ionospheric Distortion Correction". MITRE Working Paper WP-2774, 23 June 1969. (ESD-TR-69-377, Dec. 1969).

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13. ABSTRACT

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